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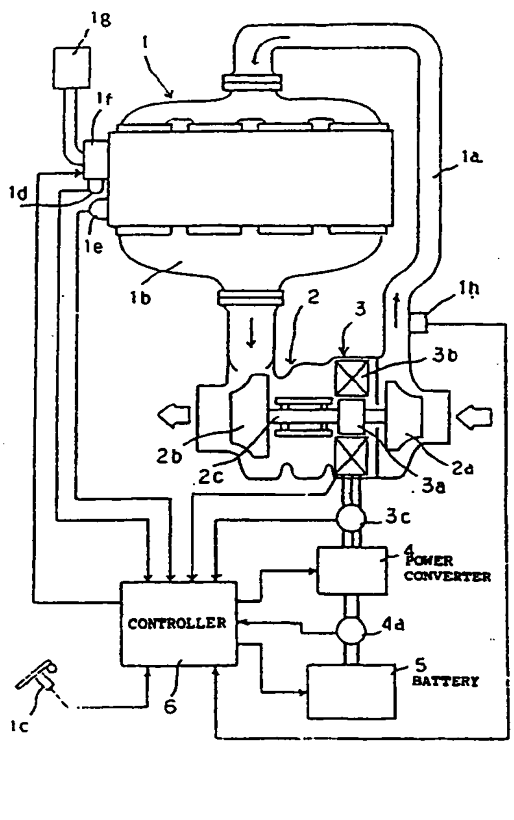
(54) Control system for turbocharger with rotary electric machine.

(57) A control system controls a turbocharger which incorporates a rotary electric machine that is operable as a motor or a generator. When the rotary electric machine operates as a motor with supplied electric power, the control system controls the amount by which the electric power is to be reduced or increased, depending on the rate of change of the rotational speed of the turbocharger within a speed control range for the turbocharger, thereby reducing the degree by which the rotational speed of the turbocharger varies.

Fig. 1



EP 0 420 704 A1

CONTROL SYSTEM FOR TURBOCHARGER WITH ROTARY ELECTRIC MACHINE

The present invention relates to a system for controlling a turbocharger mounted in an internal combustion engine, the turbocharger having a rotary electric machine mounted on the rotatable shaft thereof and operable as a motor-generator which functions as a motor or a generator.

There have heretofore been proposed various methods and systems for recovering the energy of exhaust gases emitted from internal combustion engines as drive power or electric power since the exhaust gases are high in temperature and pressure. One exhaust energy recovery system, which is disclosed in Japanese Laid-Open Patent Publication No. 63(1988)-272909, has a rotary electric machine, operable as a motor-generator, which is mounted on a turbine shaft that can be driven by the energy of exhaust gases. Supercharging operation of the rotary electric machine and fuel supply are controlled on the basis of the load condition of the engine and the depression of the accelerator pedal.

Fig. 4 of the accompanying drawings schematically shows the exhaust energy recovery system disclosed in the above publication. An engine 1 has an exhaust pipe 1b and an intake pipe 1a which are connected respectively to a turbine 2b and a compressor 2a of a turbocharger 2. A rotary electric machine 3, which is operable as a motor-generator, is mounted on a rotatable turbine shaft 2c of the turbocharger 2.

A battery 5 is connected to a controller 6 which comprises a microcomputer and has a power electric device as an input/output circuit. Depending on signals from an accelerator pedal movement sensor 1c, an engine load sensor 1d, an engine rotation sensor 1e, and a boost pressure sensor 1h, the controller 6 controls the rotary electric machine 3 as a motor with the electric power from the battery 5 to increase the boost pressure and increase the amount of supplied fuel, based on the operating conditions of the engine 1. Therefore, when a high load is imposed on the engine 1, the engine 1 can be controlled to produce an engine output power corresponding to the maximum amount of depression of the accelerator pedal. As shown in the flowchart of Fig. 5, if the accelerator pedal is depressed to a maximum stroke, i.e. if the amount of depression of the accelerator pedal is maximum, control goes from a step (a) to a step (b). There is established a speed control range L (rpm) - H (rpm) in which the rotary electric machine 3 is to operate as a motor. If the rotational speed of the turbocharger 2 (i.e., the rotational speed of the rotary electric machine 3) is lower than the lower level L (rpm) in the step (b), then the electric current supplied from the battery 5 is maximized in a step (c). If the rotational speed of the turbocharger 2 is higher than the lower level L (rpm) in the step (b), then control goes to a step (d) which determines whether it is lower than the upper level H (rpm). If the rotational speed of the turbocharger 2 is lower than the higher level H (rpm) in the step (d), but increases in a step (e), then control goes to a step (f) in which the electric current supplied from the battery 5 is reduced. If the rotational speed of the turbocharger 2 decreases in the step (e), then control goes to a step (g) in which the electric current supplied from the battery 5 remains unchanged. If the rotational speed of the turbocharger 2 reaches the upper level H (rpm) in the step (d), the supplied electric current is discontinued or reduced by a certain level, so that the rotational speed of the turbocharger 2 will not exceed the upper level H (rpm).

As described above, if the rotational speed of the turbocharger is lower than the lower level, then the supplied current is maximized to rotate the turbocharger at high speed irrespective of the degree by which the rotational speed of the turbocharger is lower than the lower level, and if the rotational speed of the turbocharger reaches the high level, then the supplied current is reduced to rotate the turbocharger at low speed irrespective of the degree by which the rotational speed of the turbocharger has increased up to the high level. With such repeated rotational speed control process, therefore, the rotational speed of the turbocharger tends to vary in a wide range as shown in Fig. 6. The rotational speed of the turbocharger does not converge in a smaller range, but is liable to be controlled unstably.

It is an object of the present invention to provide a control system for operating a rotary electric machine mounted on the rotatable shaft of a turbocharger, as a motor while controlling the rotational speed of the turbocharger to remain in a speed control range with reduced speed variations or fluctuations.

According to present invention, there is provided a control system for controlling a turbocharger mounted on an internal combustion engine on a motor vehicle, the turbocharger being combined with a rotary electric machine mounted on a rotatable shaft of the turbocharger and energizable with supplied electric power to rotate the turbocharger to control the amount of intake air to be supercharged into the engine, the control system comprising an accelerator pedal movement sensor for detecting an amount of depression of an accelerator pedal which controls an amount of fuel to be sup-

plied to the engine, means for determining whether the amount of depression of the accelerator pedal is maximum or not, based on a signal from the accelerator pedal movement sensor, means for supplying electric power to the rotary electric machine if the amount of depression of the accelerator pedal is determined as being maximum, a rotation sensor for detecting a rotational speed of the turbocharger, means for calculating a rate of change of the rotational speed of the turbocharger, based on a signal from the rotation sensor, means for calculating an amount by which the electric power to be supplied to the rotary electric machine is to be reduced or increased, depending on the calculated rate of change of the rotational speed, means for setting a speed control range for the turbocharger, and means for controlling the electric power to be supplied to the rotary electric machine based on the calculated amount by which the electric power to be supplied to the rotary electric machine is to be reduced or increased, when the rotational speed of the turbocharger is in the speed control range.

The above and other objects, features and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which a preferred embodiment of the present invention is shown by way of illustrative example.

Fig. 1 is a schematic view, partly in block form, of a system for controlling a turbocharger which incorpo rates a rotary electric machine, according to the present invention;

Fig. 2 is a flowchart of a control sequence of the system shown in Fig. 1;

Fig. 3 is a diagram showing the relationship between the rate of change of the rotational speed of the turbocharger and the electric current supplied to the rotary electric machine;

Fig. 4 is a schematic view, partly in block form, of a conventional system for controlling a turbocharger which incorporates a rotary electric machine;

Fig. 5 is a flowchart of a control sequence of the system shown in Fig. 4; and

Fig. 6 is a diagram showing variations or fluctuations in the rotational speed of the turbocharger controlled by the conventional system show in Fig. 4.

Fig. 1 shows, partly in block form, of a control system for controlling a turbocharger which incorporates a rotary electric machine, according to the present invention.

As shown in Fig. 1, an engine 1 drives a motor vehicle (not shown) with the energy produced upon combustion of fuel supplied from a fuel tank 1g by an injection pump 1f with the aid of air drawn from an intake pipe 1a. Exhaust gases produced when the fuel is combusted are discharged through an exhaust pipe 1b. The engine 1 is associated with an accelerator pedal movement sensor 1c for detecting the amount of depression of an accelerator pedal, a load sensor 1d for detecting the rack position of the fuel pump 1f, i.e., the amount of fuel supplied to the engine 1, and an engine rotation sensor le for detecting the rotational speed of the engine 1. Detected signals from these sensors 1c, 1d, 1e are transmitted to a controller 6.

A turbocharger 2 is connected to the exhaust pipe Ib and the intake pipe 1a and has a turbine 2b rotatable by the exhaust gases and a compressor 2a for supplying air under pressure to the intake pipe 1a. The turbine 2b and the compressor 2a are mechanically coupled to each other by a rotatable shaft 2c on which there is mounted a rotary electric machine 3 that is operable as a motor or a generator.

The rotary electric machine 3 has a rotor 3a supported on the rotatable shaft 2c and a stator 3b disposed around the rotor 3a. When the rotor 3a is rotated by turbine 2b driven by the exhaust gases, the stator 3b induces AC electric power which is transmitted through a power converter 4 to a battery 5. When the rotor 3a is rotated by electric power supplied from the battery 5 through the power converter 4 to the stator 3b, the compressor 2a rotates to compress intake air and charges compressed air through the intake air 1a into the engine 1. The pressure in the intake pipe 1a is detected by a boost pressure sensor 1h, which applies a signal that represents the boost pressure developed in the intake pipe 1a by the compressor 2a to the controller 6.

The power converter 4 serves to convert the AC electric power from the stator 3b into DC electric power to charge the battery 5 when the rotary electric machine 3 operates as a generator, or to convert DC electric power from the battery 5 into AC electric power to energize the rotary electric machine 3 as a motor. Therefore, the power converter 4 has rectifying and smoothing circuits for converting AC electric power into DC electric power, an inverter for converting DC electric power into AC electric power, and a power converter device such as a booster circuit. The frequency of AC electric power into which DC electric power is to be converted, and the voltage and magnitude of the AC electric power are controlled by commands from the controller 6. An AC meter 3c is connected between the stator 3b and the power converter 4, for measuring the voltage, current, and phase of the AC electric power converted by the power converter 4 and supplied to the stator 3b. A DC meter 4a is connected between the power converter 4 and the battery 5, for measuring the voltage and current of the DC electric power converted

by the power converter 4. Measured values from the AC and DC meters 3c, 4a are sent to the controller 6.

The controller 6 comprises a microcomputer which has a central processing unit for calculating an amount of fuel to be supplied, a required amount of electric power, and a required boost pressure, based on operating conditions of the engine 1 and signals from the various sensors, a memory for storing the calculated values, a memory for storing control programs for the engine 1 and the rotary electric machine 3, and an input/output unit for receiving various input signals and transmitting various control signals. The rotational speed of the rotary electric machine 3, i.e., the rotational speed of the turbocharger 2, which is detected based on the frequency of a counterelectromotive force induced in the stator 3b when the rotary electric machine 3 rotates, is supplied to the controller 6.

Fig. 2 shows a control sequence of the control system shown in Fig. 1. Fig. 3 shows the relationship between an electric current supplied to the rotary electric machine 3 and a rate of change of the rotational speed of the rotary electric machine 3, i.e., the turbocharger 2. In Fig. 2, a step (1) determines whether the amount of depression of the accelerator pedal is maximum or not. If maximum, then control goes to a step (2), and if not, then control goes to a step (6). The step (6) compares a target boost pressure Pt, which is determined from the amount of depression of the accelerator pedal and the rotational speed of the engine 1, with an actual boost pressure PB. If the difference between the compared boost pressures Pt, PB is larger than a boost pressure difference KB used to determine acceleration (accelerating condition), then an electric current to be supplied, which corresponds to the boost pressure difference, is calculated in a step (11), and control goes to a flow (A). If the boost pressure difference is smaller than the boost pressure difference KB, then control goes to a step (12) for determining a mode.

If control goes from the step (1) to the step (2), the step (2) determines whether the rotational speed of the turbocharger 2 has been higher than L (rpm) (the lower limit level of a speed control range when the rotary electric machine 3 is to operate a motor) in the past. If yes, then control goes to a step (7) which determines whether present rotational speed of the turbocharger 2 is lower than L (rpm). If the rotational speed is lower than L (rpm), then control goes to a step (13) which determines an electric current to be supplied which corresponds to the rotational speed of the engine 1, and determines an electric current to be reduced or increased depending on the rate of change of the rotational speed of the turbocharger as shown in Fig. 3, for example, thereby calculating an electric current to be supplied. Thereafter, control goes to the flow (A).

If the rotational speed is higher than L (rpm) in the step (7), then the same process as when the rotational speed of the turbocharger 2 has not been higher than L (rpm) in the past is effected in a step (8), as described later.

If the rotational speed of the turbocharger 2 has not been higher than L (rpm) in the past in the step (2), then control goes from the step (2) to a step (3) which compares the present rotational speed of the turbocharger 2 with L (rpm). If the present rotational speed of the turbocharger is lower than L (rpm), then the electric current to be supplied to the rotary electric machine 3 is maximized in a step (4), and then the rotary electric machine 3 is energized with the maximum electric current in a step (5).

If the rotational speed of the turbocharger 2 is higher than L (rpm) in the step (3), then the rotational speed of the turbocharger 2 is compared with H (rpm) (the upper limit level of the speed control range when the rotary electric machine 3 is to operate a motor). If the rotational speed has reached H (rpm), then the rotary electric machine 3 is de-energized in a step (14). If the rotational speed has not yet reached H (rpm), then a rate of change of the rotational speed of the turbocharger 2 is determined from the present rotational speed of the turbocharger 2 and the previous rotational speed thereof in a step (9). In a next step (10), a corresponding electric current to be reduced or increased is determined, thus calculating an electric current to be supplied in a step (10). The rotary electric machine 3 is energized with the calculated electric current according to the flow (A).

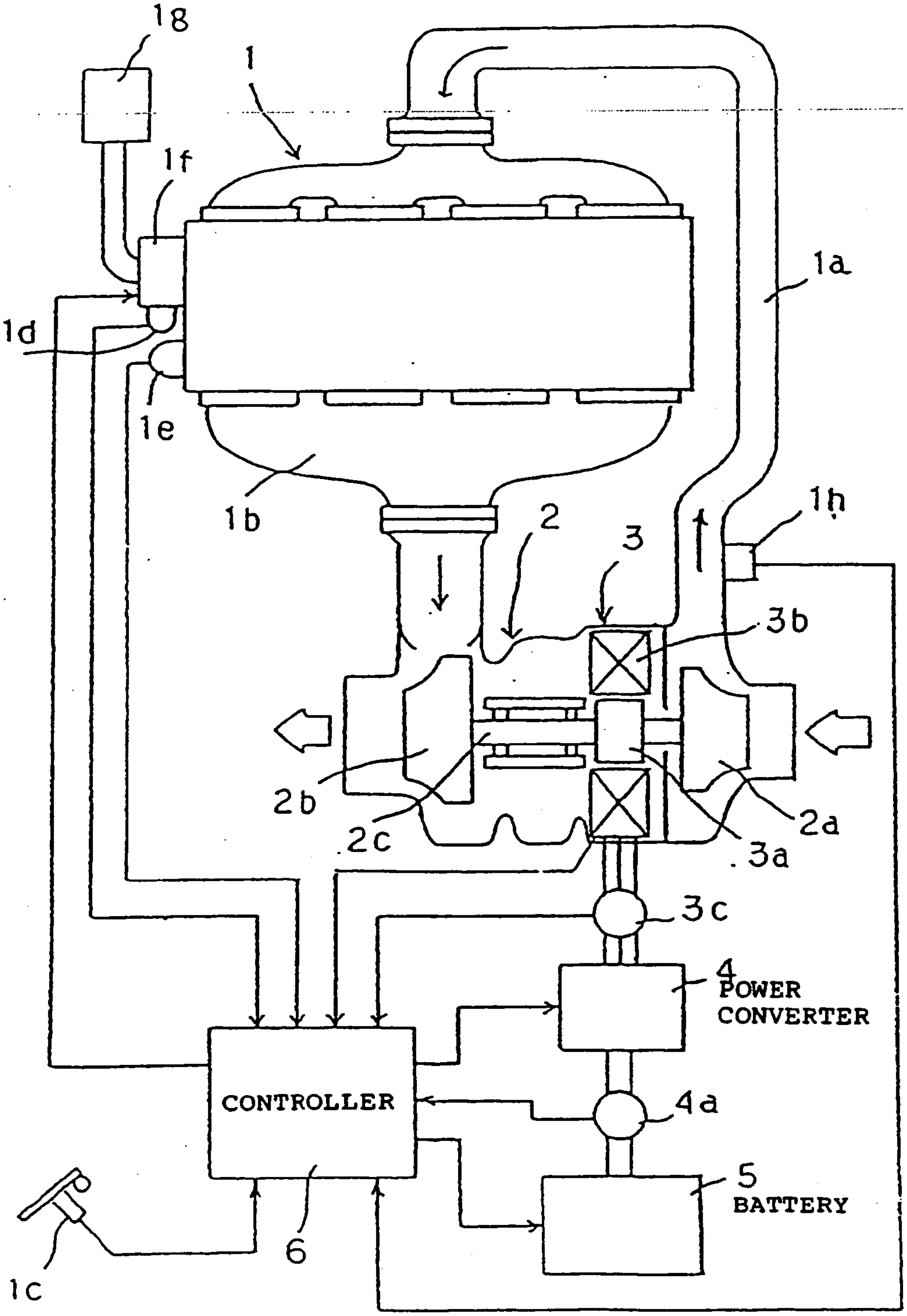
With the present invention, as described above, when the rotational speed of the turbocharger is in the speed control range, an appropriate reduced or increased electric current is supplied to the rotary electric machine depending on a rate of change, i.e., increase or reduction, of the rotational speed of the turbocharger. Therefore, the degree by which the rotational speed of the turbocharger varies is reduced. Since the electric current supplied to the rotary electric machine is suitably controlled, the consumption of electric power by the rotary electric machine is also reduced.

Although a certain preferred embodiment has been shown and described, it should be understood that many changes and modifications may be made therein without departing from the scope of the appended claims.

Claims

1. A control system for controlling a turbocharger mounted on an internal combustion engine on a motor vehicle, the turbocharger being combined with a rotary electric machine mounted on a rotatable shaft of the turbocharger and energizable with supplied electric power to rotate the turbocharger to control the amount of intake air to be supercharged into the engine, said control system comprising:
an accelerator pedal movement sensor for detecting an amount of depression of an accelerator pedal which controls an amount of fuel to be supplied to the engine;
means for determining whether the amount of depression of the accelerator pedal is maximum or not, based on a signal from said accelerator pedal movement sensor;
means for supplying electric power to the rotary electric machine if the amount of depression of the accelerator pedal is determined as being maximum;
a rotation sensor for detecting a rotational speed of the turbocharger;
means for calculating a rate of change of the rotational speed of the turbocharger, based on a signal from said rotation sensor;
means for calculating an amount by which the electric power to be supplied to the rotary electric machine is to be reduced or increased, depending on the calculated rate of change of the rotational speed;
means for setting a speed control range for the turbocharger; and
means for controlling the electric power to be supplied to the rotary electric machine based on said calculated amount by which the electric power to be supplied to the rotary electric machine is to be reduced or increased, when the rotational speed of the turbocharger is in said speed control range.
2. A control system according to claim 1, wherein said means for supplying electric power to the rotary electric machine comprises means for supplying maximum electric power to the rotary electric machine if the rotational speed of the turbocharger has not been reached said speed control range.
3. A control system according to claim 1, wherein said means for supplying electric power to the rotary electric machine comprises means for cutting off the supply of electric power to the rotary electric machine if the rotational speed of the turbocharger has exceeded said speed control range.

Fig. 1



1g
1
1f
1a
1d
1e
1b
1h
2
3
3b
2b
2c
2a
3a
3c
4
POWER
CONVERTER
CONTROLLER
4a
5
BATTERY
6
1c

Fig.2

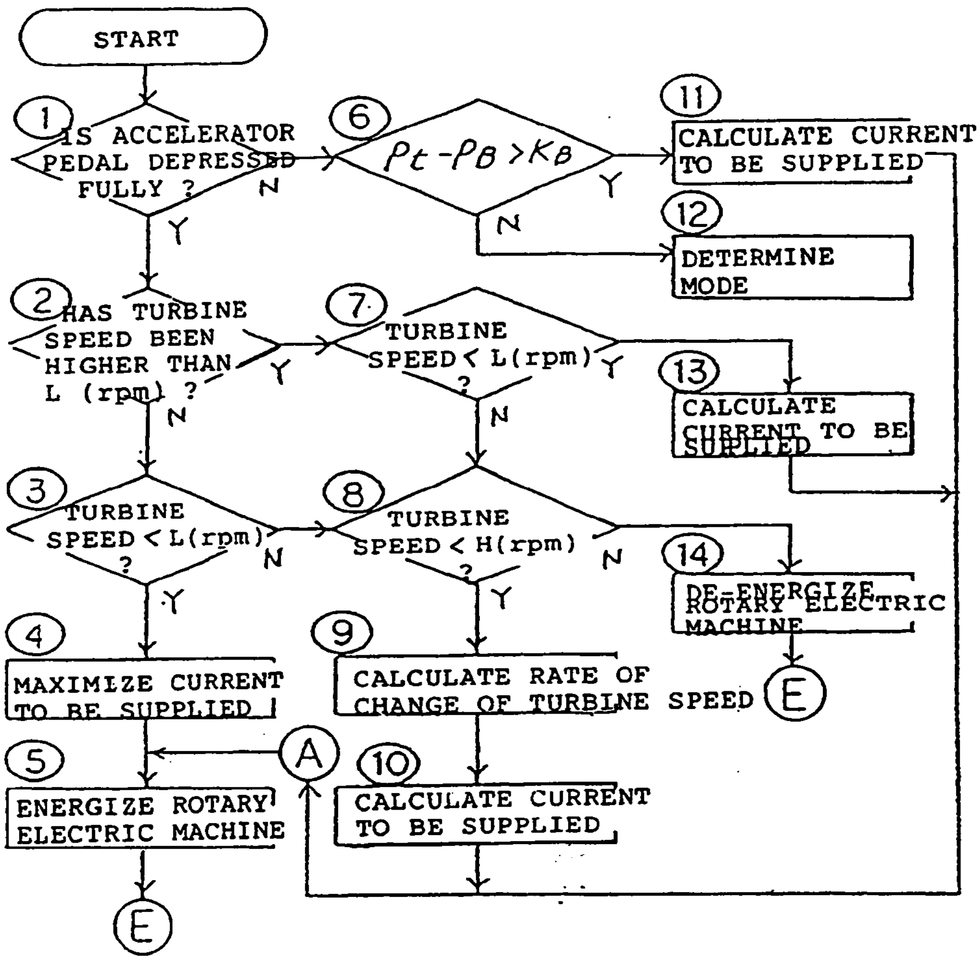

START
1
IS ACCELERATOR PEDAL DEPRESSED FULLY ?
N
Y
6
$P_t - P_B > K_B$
Y
N
11
CALCULATE CURRENT TO BE SUPPLIED
12
DETERMINE MODE
2
HAS TURBINE SPEED BEEN HIGHER THAN L (rpm) ?
Y
N
7
TURBINE SPEED < L(rpm) ?
Y
N
13
CALCULATE CURRENT TO BE SUPPLIED
3
TURBINE SPEED < L(rpm) ?
N
Y
8
TURBINE SPEED < H(rpm) ?
N
Y
14
DE-ENERGIZE ROTARY ELECTRIC MACHINE
E
4
MAXIMIZE CURRENT TO BE SUPPLIED
9
CALCULATE RATE OF CHANGE OF TURBINE SPEED
5
A
10
ENERGIZE ROTARY ELECTRIC MACHINE
CALCULATE CURRENT TO BE SUPPLIED
E

Fig.3

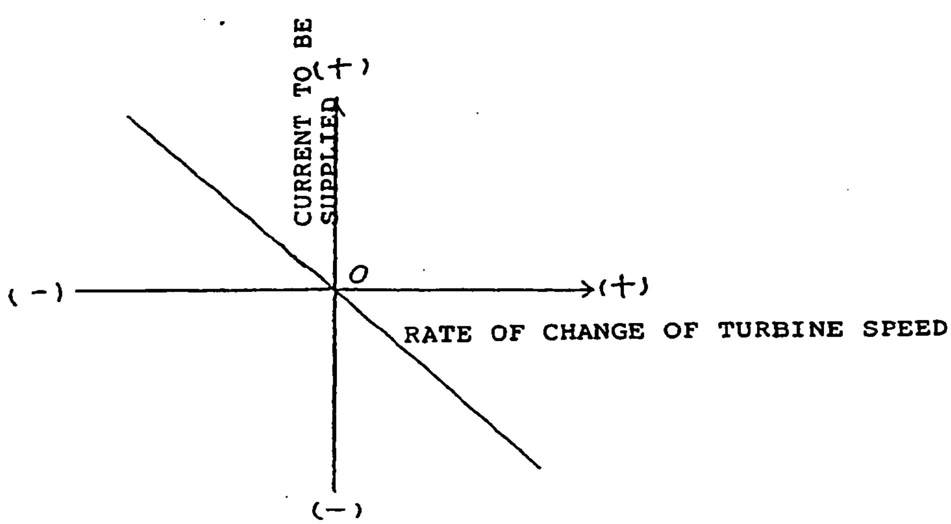

CURRENT TO BE SUPPLIED
(+)
(−)
O
(+)
RATE OF CHANGE OF TURBINE SPEED
(−)

Fig. 4

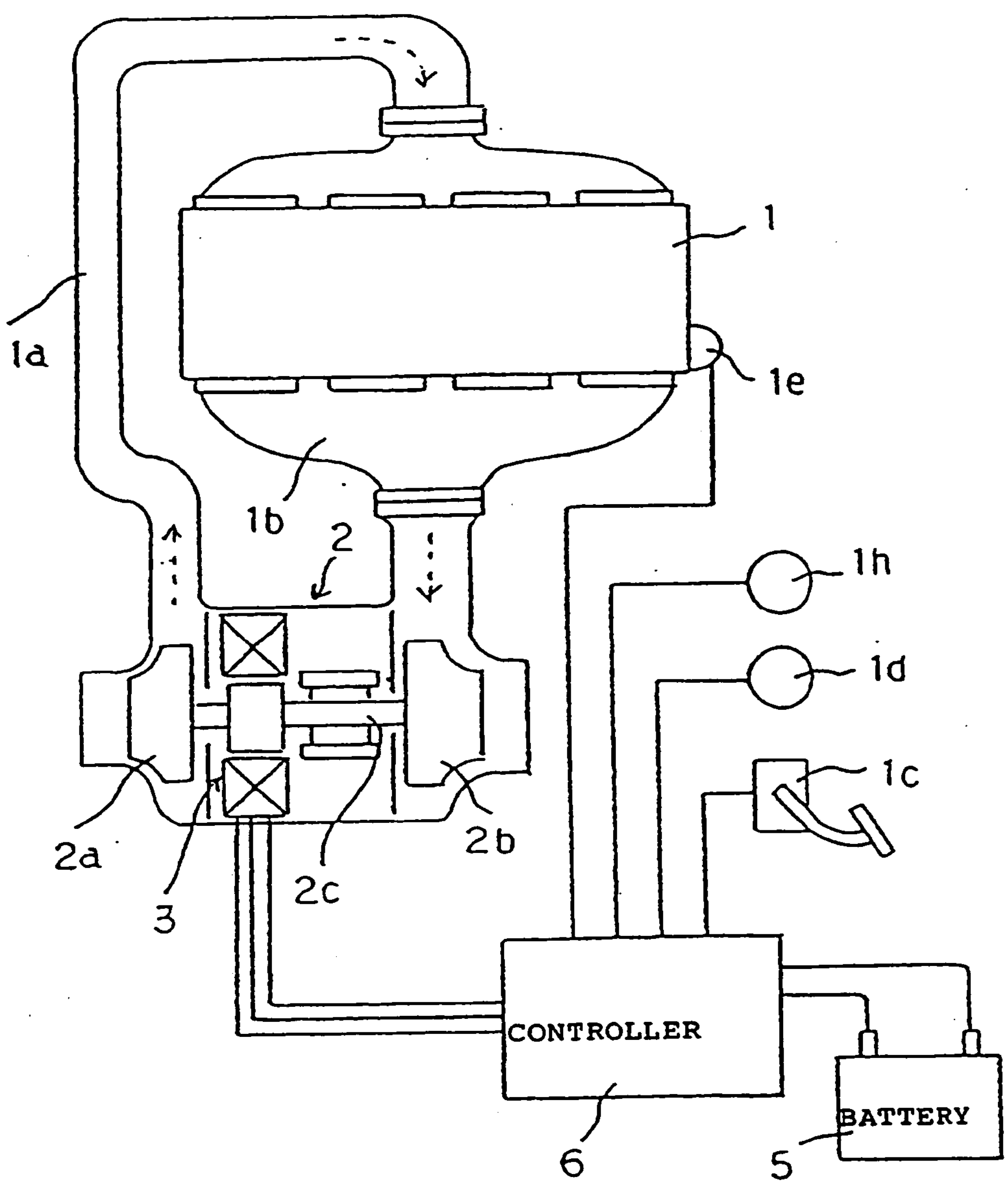


Fig. 5

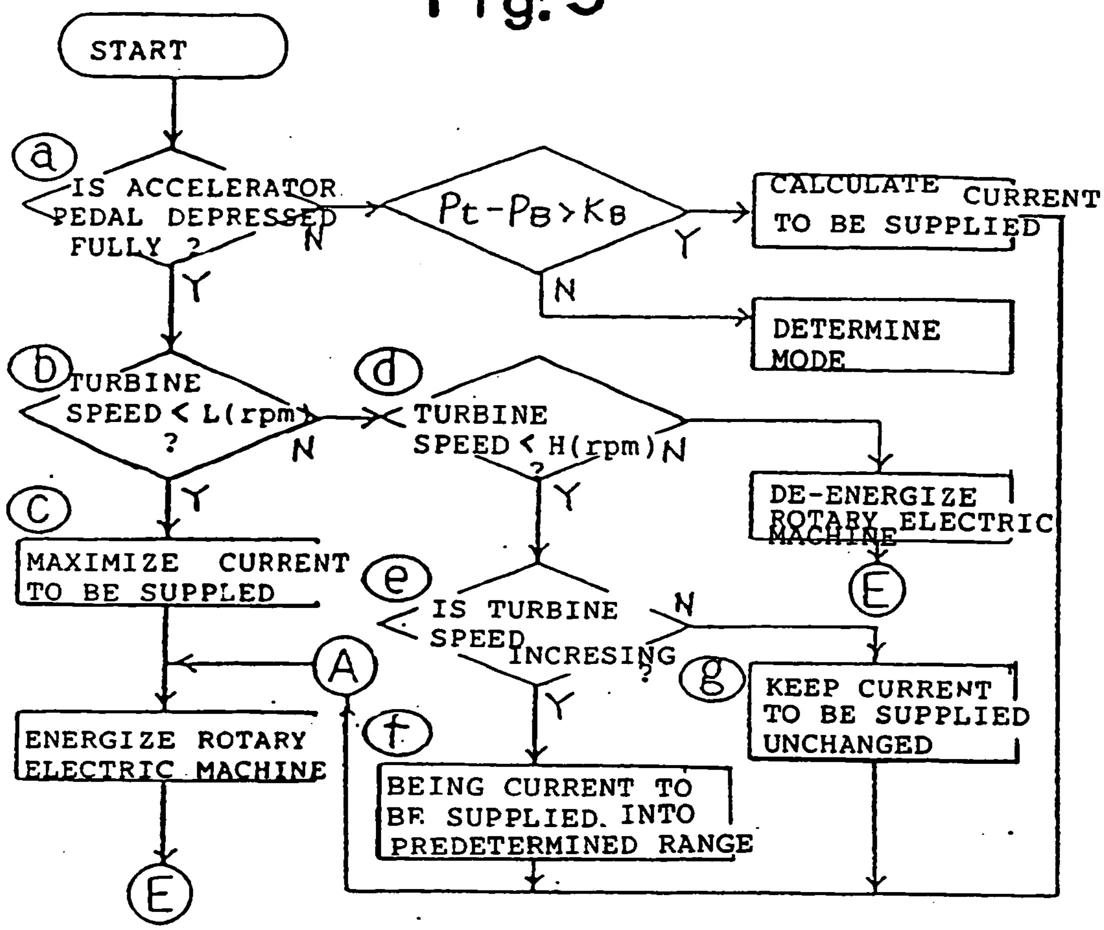
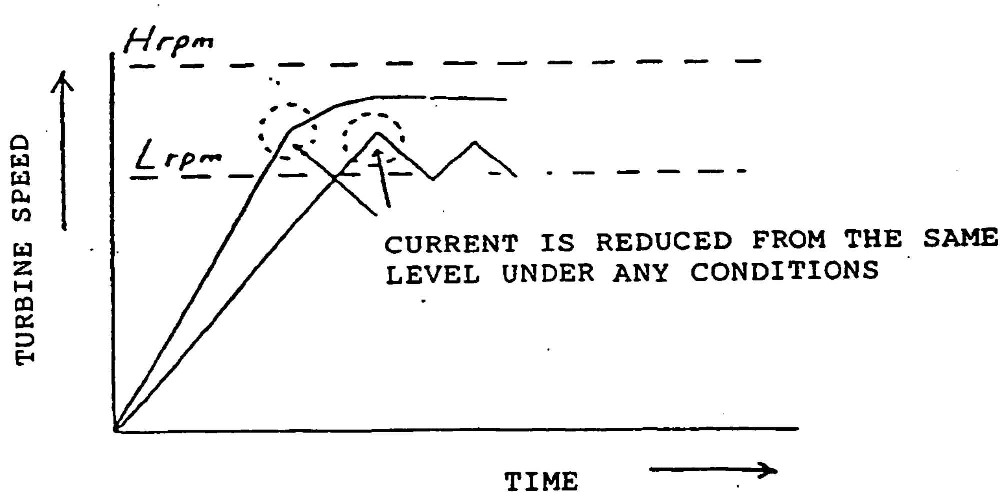

START
a
IS ACCELERATOR PEDAL DEPRESSED FULLY ?
N
Y
$P_t - P_B > K_B$
Y
N
CALCULATE CURRENT TO BE SUPPLIED
DETERMINE MODE
b
TURBINE SPEED < L(rpm) ?
N
Y
d
TURBINE SPEED < H(rpm) ?
N
Y
DE-ENERGIZE ROTARY ELECTRIC MACHINE
E
c
MAXIMIZE CURRENT TO BE SUPPLED
e
IS TURBINE SPEED INCRESING ?
N
Y
A
g
KEEP CURRENT TO BE SUPPLIED UNCHANGED
ENERGIZE ROTARY ELECTRIC MACHINE
f
BEING CURRENT TO BE SUPPLIED INTO PREDETERMINED RANGE
E

Fig. 6


Hrpm
Lrpm
TURBINE SPEED
CURRENT IS REDUCED FROM THE SAME LEVEL UNDER ANY CONDITIONS
TIME

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 31 0731

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	EP-A-0 079 100 (MICROTURBO S.A.) * the whole document *	1-3	F 02 B 37/14
A	EP-A-0 311 457 (ISUZU MOTORS LIMITED) * column 5, line 34 - column 6, line 17; figures 1, 2 *	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
F 02 B

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	18 December 90	HAKHVERDI M.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
Y: particularly relevant if combined with another document of the same catagory
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P: intermediate document
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L: document cited for other reasons

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